# A Random Walk to a Career in Nuclear Physics

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Physics & Biomedical Careers Panel
Career Counseling and Professional Development
The City College of New York
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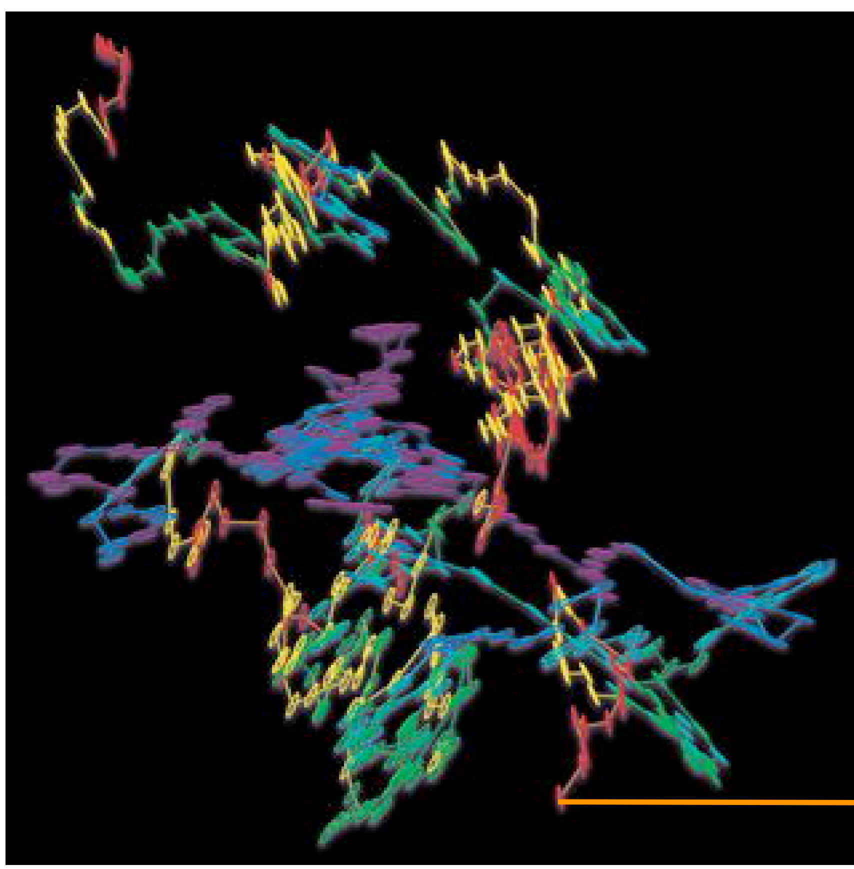
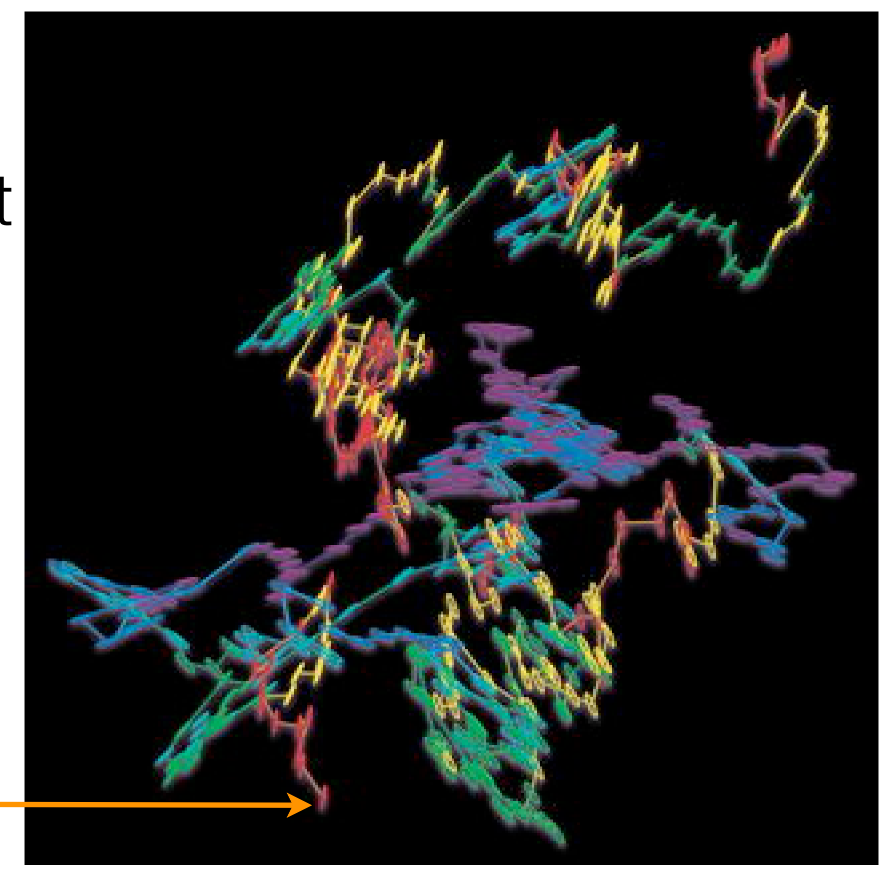
# What am I and how did I get here?

- When people ask me, I say I'm a "Nuclear Physicist"
  - No energy, no bombs: I'm really more of a "Particle Physicist"...
- People assume I did this since childhood
  - I was definitely interested as a kid, but it was not a straight path



Fair to say that I "bounced around" a bit before choosing this

And it hasn't always been a straight line since then



# Here is where I work

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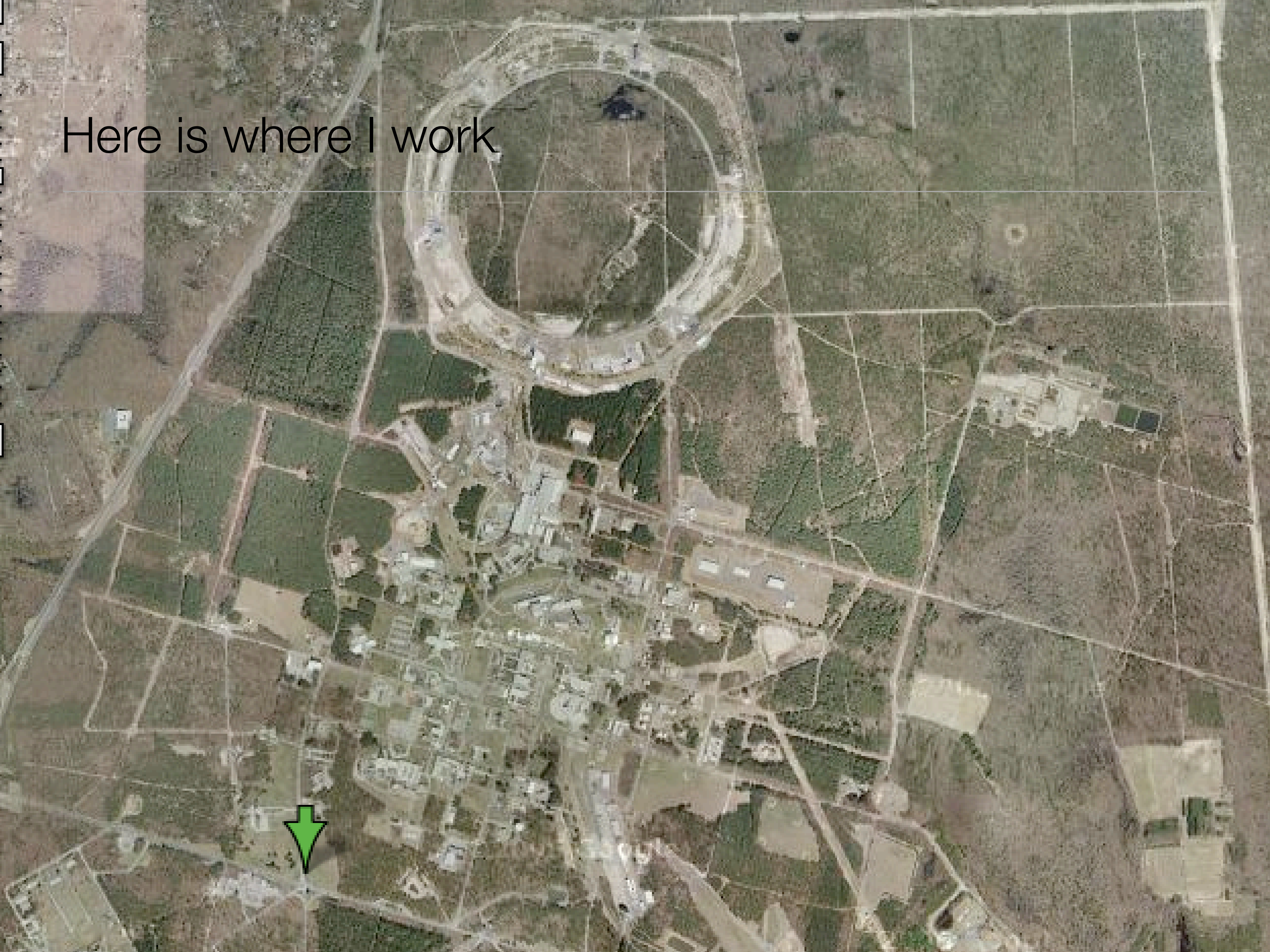
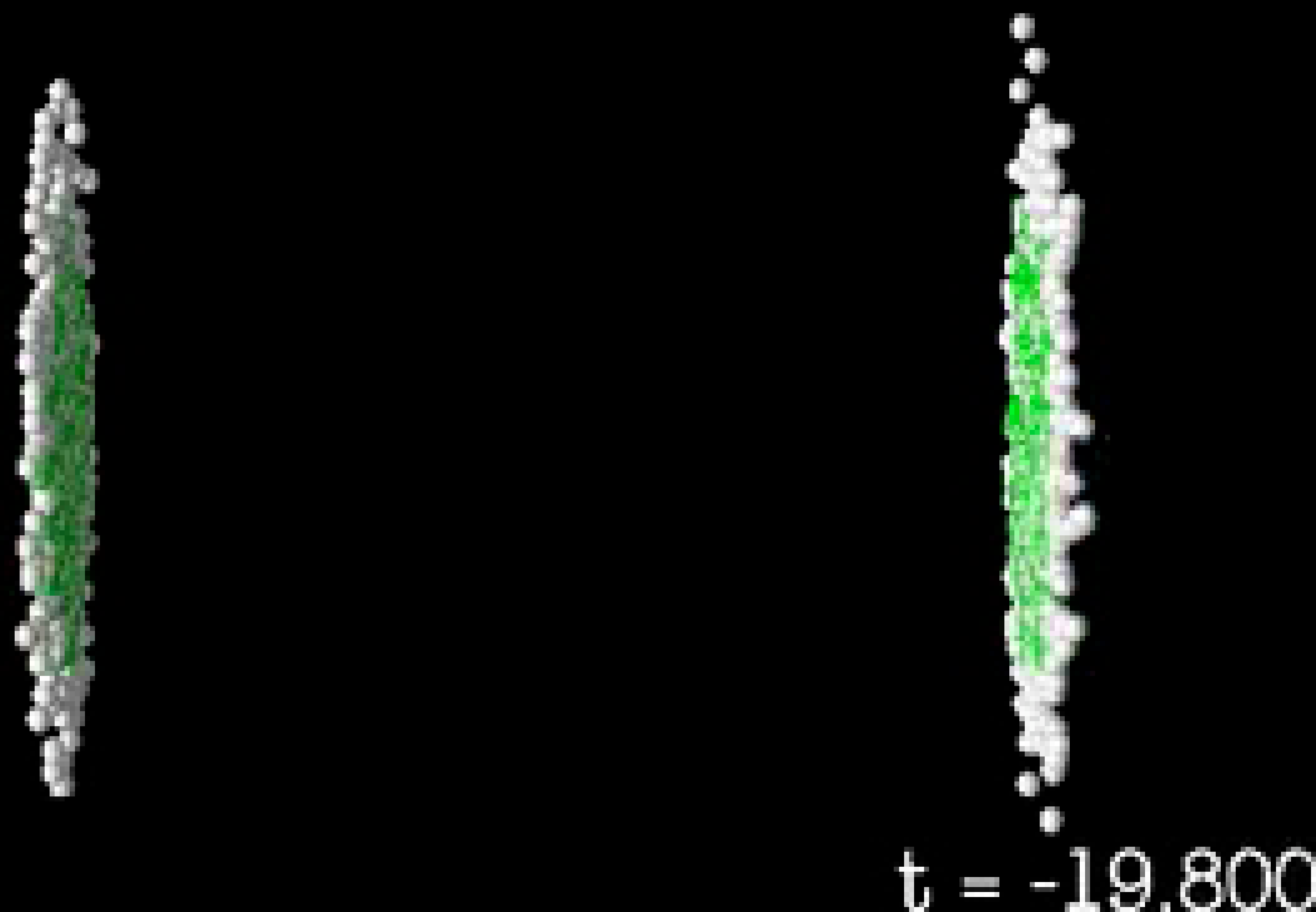
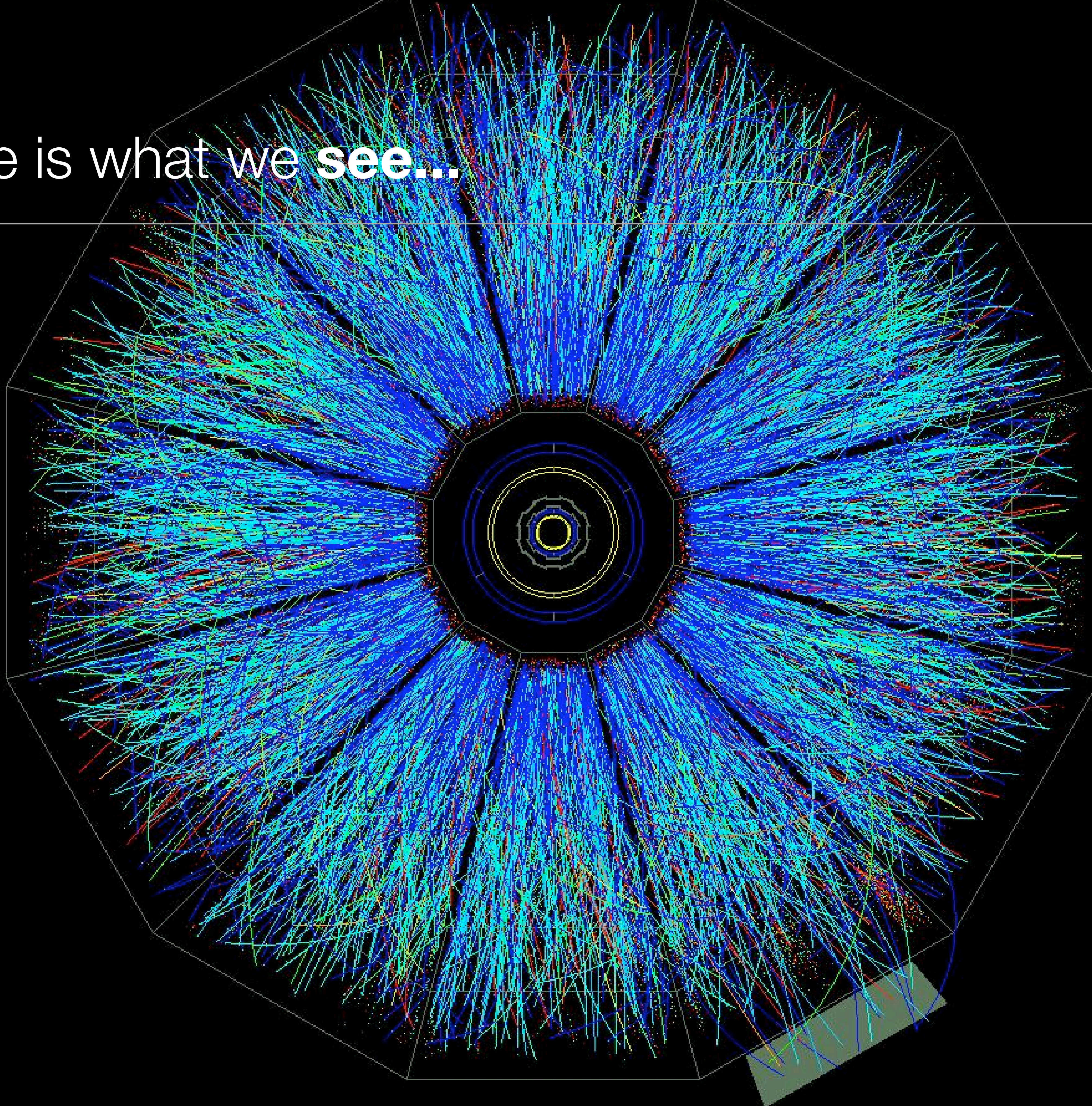


# Here is what we do...“heavy ion physics” (gold ions)

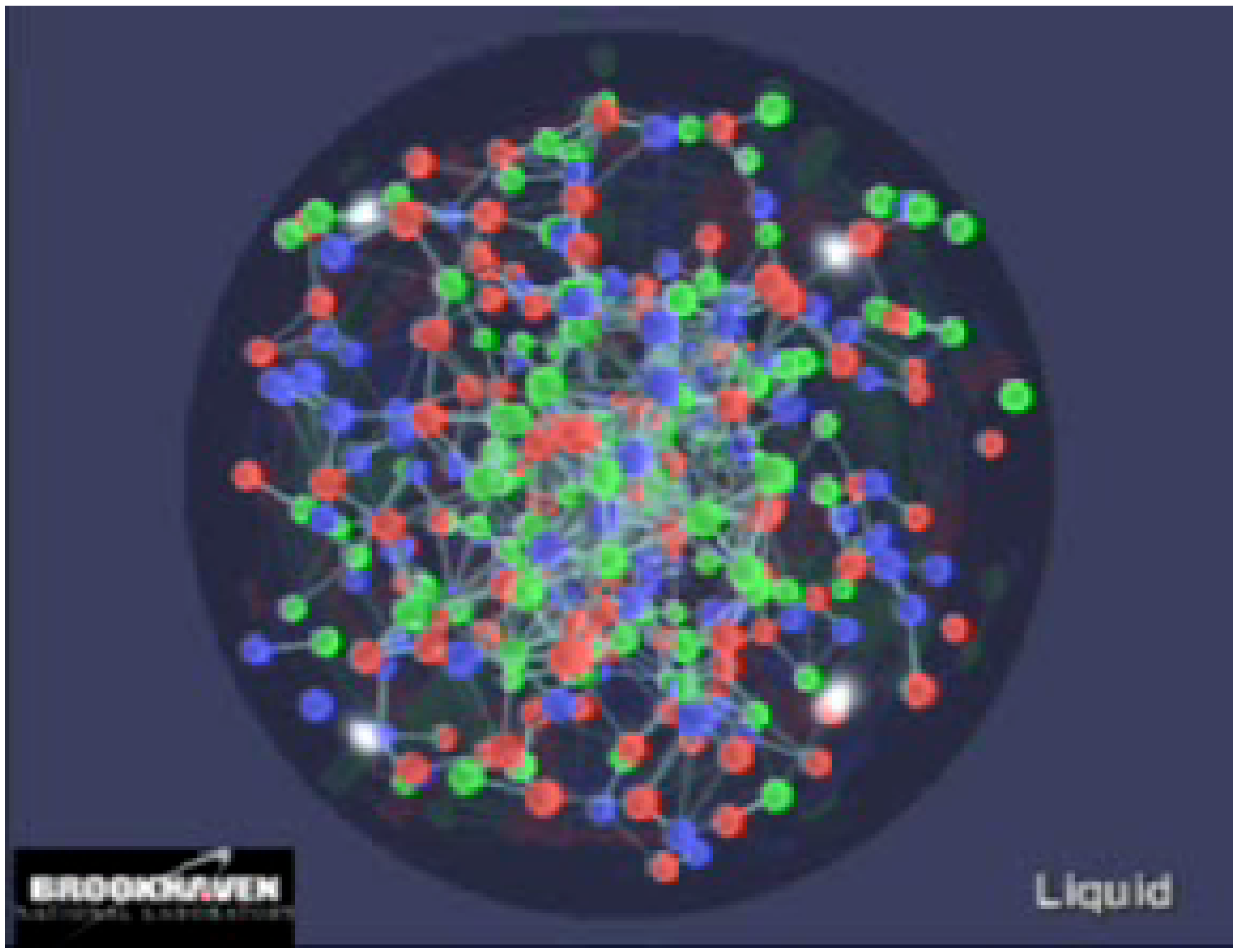
# Here is what we do (scientist's conception...)

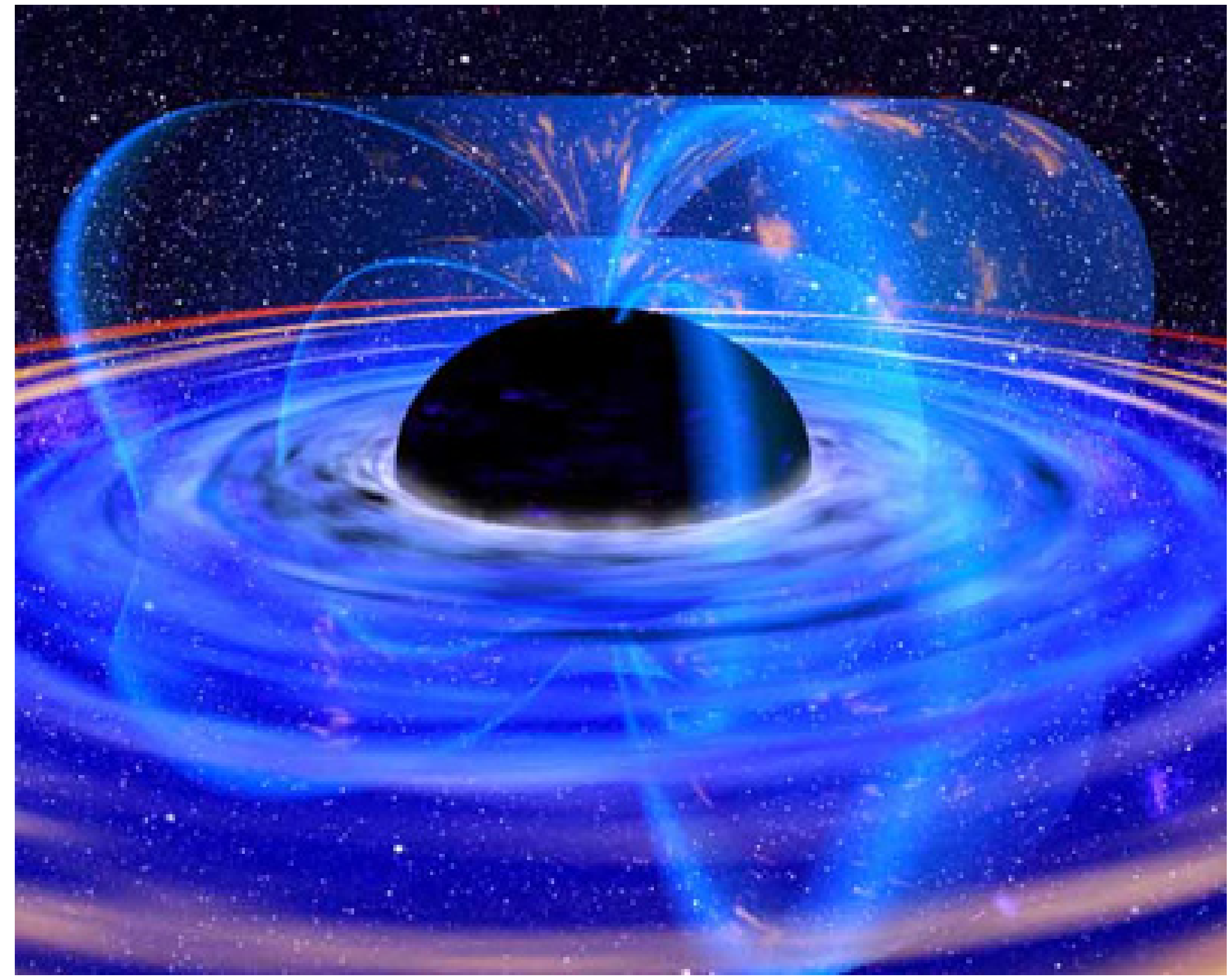


# Here is what we **see...**



Here is what we say...



We make one of the most perfect fluids found in nature, one which may lead to interesting connections between

**quarks, gluons ↔ string theory/black holes**

ANTICANCER BLOCKBUSTER? • RISE AND FALL OF THE SLIDE RULE

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# Quark Soup

PHYSICISTS RE-CREATE THE LIQUID STUFF OF **THE EARLIEST UNIVERSE**

Stopping **Alzheimer's**

Birth of **the Amazon**

Future **Giant Telescopes**

# And you may ask yourself “Well...how did I get here?”

# A start in New England...


Started grad school at MIT in ‘93

a “missing” year...

Undergrad at Yale ‘92

# Major Changes

- Started college with no major, and bounced around
  - Random walk...
- Literature major - liked Postmodern Theory more than the literature
- A brief interlude in Physics
  - None in high school (don't ask...took photo instead)
  - Nearly failed out of my first semester
- Philosophy
  - Plato, Pristotle, Hume, Kant, Russell, Wittgenstein.
- Graduated in Political Science (focus in Political Theory)
  - Senior theses on Spinoza and Maimonides, and John Stuart Mill...

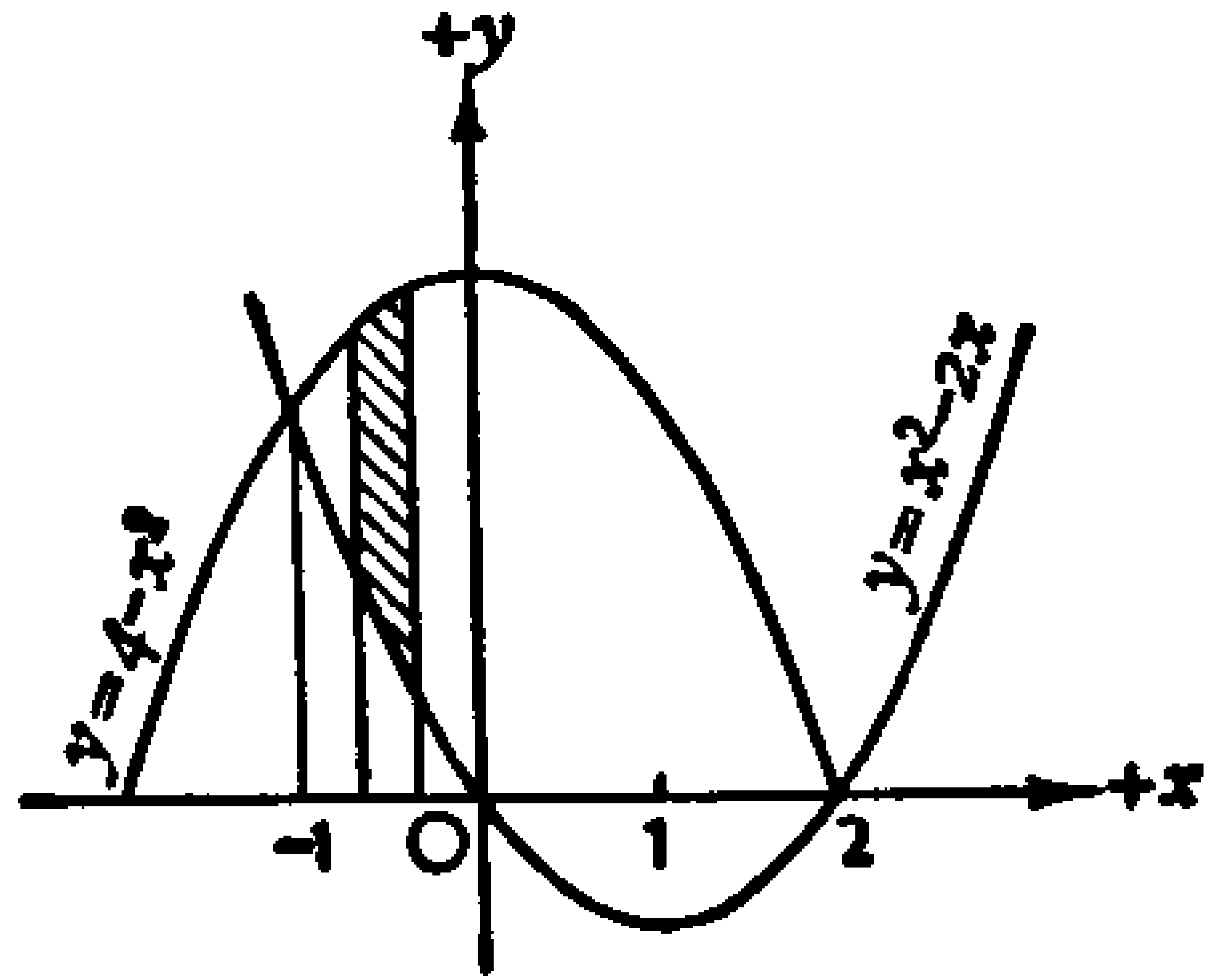
A little **p**ainful, but you only go to college once!

# The Shift to Physics

- Did well enough in Freshman calc to try physics
  - Saw how well that went...
- Then after the “P” adventures, had a revelation:
  - Philosophy was the intellectual search for truth
  - Political science looked for truth in human behavior
  - More interested in the particles & fields & waves in my textbooks!
  - Started reading a lot, and talking to math/physics friends
- Decided to “try” physics again
  - Finished freshman physics in my junior year and started reading a *lot*

# Lots of math

- Series expansions
- Single variable calculus
- Multi-variable calculus
- Linear (matrix) algebra
- Complex analysis
- etc. etc.




- No way to get to physics without a lot of math!
- Was a good excuse for a 21-year old to drink lots of coffee!

# Research, Research, Research

- Lucky break - I was an “old” guy in a sophomore class
  - Good study habits, did a bit better than my peers
  - Got on my prof’s radar
- End of my senior year, decided to risk it all
  - Give up applying for grad school, law school, etc.
  - Got a research job starting spring break
- Led to a summer job and an offer to help me get ready for applying to grad school during the next year
  - Had to teach myself FORTRAN, etc, and learn enough particle physics to simulate a proposed detector for RHIC (PHOBOS)
  - Took more physics & math courses
- Doing research was the <u>essential</u> factor to getting from college to grad school - any research topic is better than none!

# Across the water...

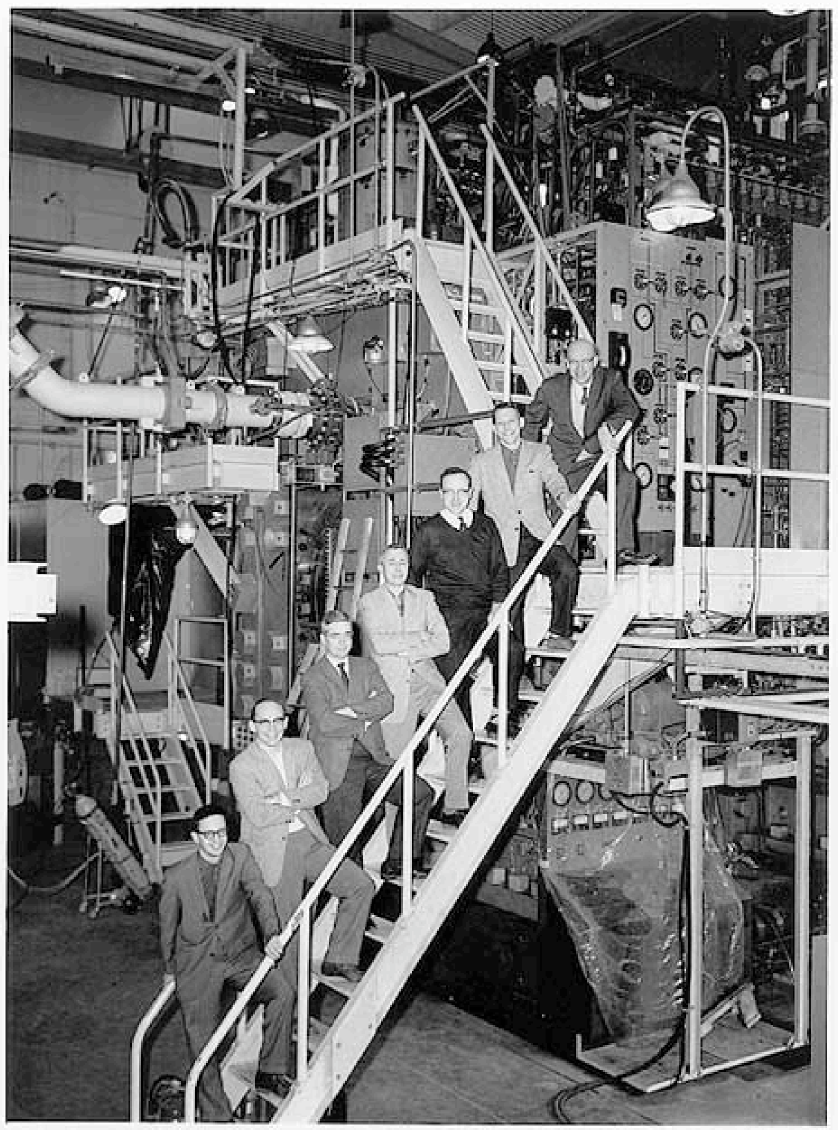
After a few false starts with a research project at MIT, ended up on a plane to Geneva, Switzerland. Stayed for 2.5 years...

# CERN (where I’m heading back to now...)

# Postdoc & After

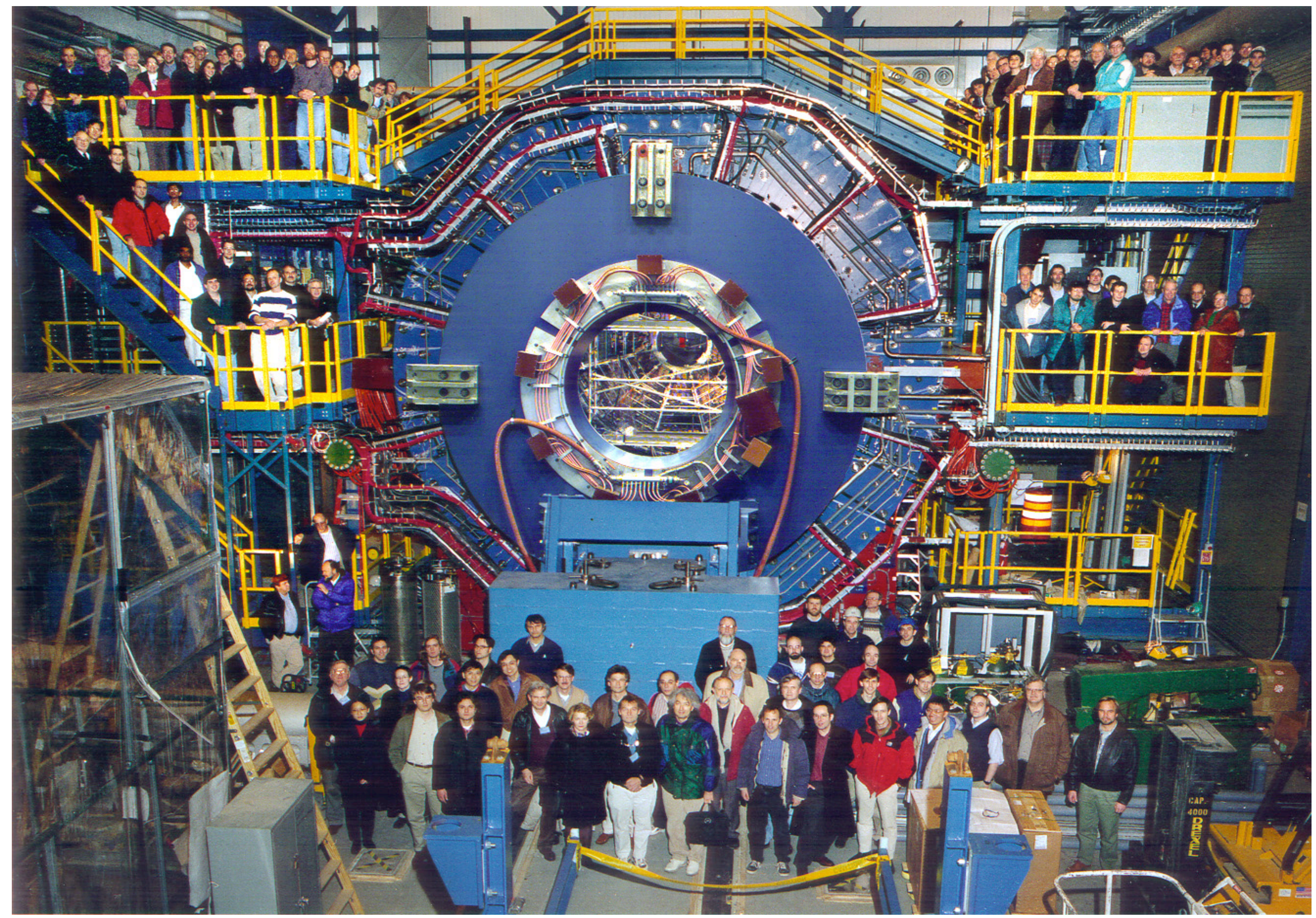
- After graduation, worked down the street from here at Columbia, from 1998-1999
  - I was a “post-doc”: a guy with a PhD who does the work the professor says that *he* is doing
  - Essential training, networking, learning, etc. (and more $ than being a student!)
- In 1999 I got a position at Brookhaven National Lab
  - Working on a “small” experiment at a new collider (same one I worked on as an undergraduate)
  - A great seven years working at RHIC
  - Now moving research focus back to CERN to work on the LHC

# Big Physics at Brookhaven



Omega-minus group: (T to B) Ralph Shutt, Jack Jensen, Medford Webster, William Tuttle, William Fowler, Donald Brown, Nicolas P. Samios

1963



2007

# A Collective Effort

- On a (nearly) daily basis, we deal with
  - Scientists (undergraduates, PhD students, postdocs, faculty, scientific staff)
  - Technical staff (software & computing engineers, detector maintenance, accelerator operators, safety monitors, surveyors)
  - Administrators (office staff, staff services, scientific support, guest support)
  - Public Relations (BNL PR, journalists, bloggers...)
- BNL is a very diverse place
  - Physics, Chemistry, Biology, Medicine, Space Science, National Security, Energy Research,...

# How I use my degree

- The core of my job is to “be” a physicist
  - Think of interesting ways (experiments) to understand the physical laws (theories) which shape the world around us
- “Doing” physics requires many different activities
  - Build experiments, meetings, write software, meetings, write papers (with 100’s of colleagues sometimes), meetings, go to conferences
- Combination of scientific and non-scientific thinking
  - Remember those meetings?
  - Simple human interactions are often more important than being “right”
  - Lots of explaining what we do to people who support us (government, public)
- Not just a lot of math

# And you may find yourself in another part of the world

**For work, we get to travel all over the world...**
**(stars are a partial travelogue of last few years...)**

# The Real Payoff

Standard Model of

## FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a quantum theory that summarizes our current knowledge of the physics of fundamental particles and fundamental interactions (interactions are manifested by forces and by decay rates of unstable particles).

### FERMIONS
matter constituents
spin = 1/2, 3/2, 5/2, ...

**Leptons** spin =1/2

| Flavor | Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| $\nu_L$ lightest neutrino* | $(0-0.13)\times10^{-9}$ | 0 |
| e electron | 0.000511 | –1 |
| $\nu_M$ middle neutrino* | $(0.009-0.13)\times10^{-9}$ | 0 |
| $\mu$ muon | 0.106 | –1 |
| $\nu_H$ heaviest neutrino* | $(0.04-0.14)\times10^{-9}$ | 0 |
| $\tau$ tau | 1.777 | –1 |

**Quarks** spin =1/2

| Flavor | Approx. Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| u up | 0.002 | 2/3 |
| d down | 0.005 | –1/3 |
| c charm | 1.3 | 2/3 |
| s strange | 0.1 | –1/3 |
| t top | 173 | 2/3 |
| b bottom | 4.2 | –1/3 |

*See the neutrino paragraph below.

**Spin** is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $=1.05\times10^{-34}$ J s.

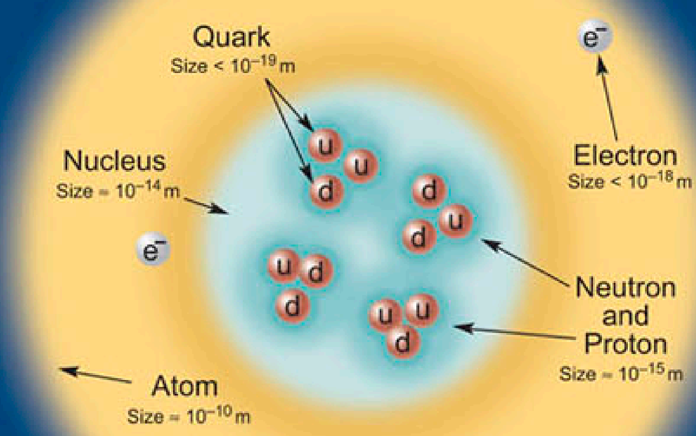
**Electric charges** are given in units of the proton's charge. In SI units the electric charge of the proton is $1.60\times10^{-19}$ coulombs.

**The energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/$c^2$ (remember $E = mc^2$) where 1 GeV = $10^9$ eV $=1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/$c^2$ = $1.67\times10^{-27}$ kg.

**Neutrinos**
Neutrinos are produced in the sun, supernovae, reactors, accelerator collisions, and many other processes. Any produced neutrino can be described as one of three neutrino flavor states $\nu_e$, $\nu_\mu$, or $\nu_\tau$, labelled by the type of charged lepton associated with its production. Each is a defined quantum mixture of the three definite mass neutrinos $\nu_L$, $\nu_M$, and $\nu_H$ for which currently allowed mass ranges are shown in the table. Further exploration of the properties of neutrinos may yield powerful clues to puzzles about matter and antimatter and the evolution of stars and galaxy structures.

**Matter and Antimatter**
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., $Z^0$, $\gamma$, and $\eta_c = c\bar{c}$ but not $K^0 = d\bar{s}$) are their own antiparticles.

### Structure within the Atom




If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

### BOSONS
force carriers
spin = 0, 1, 2, ...

**Unified Electroweak** spin = 1

| Name | Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| $\gamma$ photon | 0 | 0 |
| $W^-$ | 80.39 | –1 |
| $W^+$ W bosons | 80.39 | +1 |
| $Z^0$ Z boson | 91.188 | 0 |

**Strong (color)** spin =1

| Name | Mass GeV/$c^2$ | Electric charge |
|---|---|---|
| g gluon | 0 | 0 |

**Color Charge**
Only quarks and gluons carry "strong charge" (also called "color charge") and can have strong interactions. Each quark carries three types of color charge. These charges have nothing to do with the colors of visible light. Just as electrically-charged particles interact by exchanging photons, in strong interactions, color-charged particles interact by exchanging gluons.

**Quarks Confined in Mesons and Baryons**
Quarks and gluons cannot be isolated – they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs. The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge.

Two types of hadrons have been observed in nature **mesons** $q\bar{q}$ and **baryons** qqq. Among the many types of baryons observed are the proton (uud), antiproton ($\bar{u}\bar{u}\bar{d}$), neutron (udd), lambda $\Lambda$ (uds), and omega $\Omega^-$ (sss). Quark charges add in such a way as to make the proton have charge 1 and the neutron charge 0. Among the many types of mesons are the pion $\pi^+$ ($u\bar{d}$), kaon $K^-$ ($s\bar{u}$), $B^0$ ($d\bar{b}$), and $\eta_c$ ($c\bar{c}$). Their charges are +1, –1, 0, 0 respectively.

### Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

| Property | Gravitational Interaction | Weak Interaction (Electroweak) | Electromagnetic Interaction | Strong Interaction |
|---|---|---|---|---|
| Acts on: | Mass – Energy | Flavor | Electric Charge | Color Charge |
| Particles experiencing: | All | Quarks, Leptons | Electrically Charged | Quarks, Gluons |
| Particles mediating: | Graviton (not yet observed) | $W^+$ $W^-$ $Z^0$ | $\gamma$ | Gluons |
| Strength at $10^{-18}$ m | $10^{-41}$ | 0.8 | 1 | 25 |
| Strength at $3\times10^{-17}$ m | $10^{-41}$ | $10^{-4}$ | 1 | 60 |

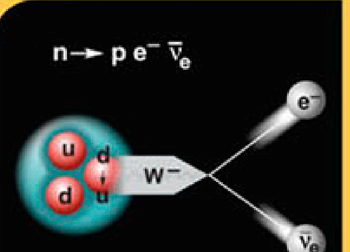
Visit the award-winning web feature *The Particle Adventure* at
**ParticleAdventure.org**

This chart has been made possible by the generous support of:
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory

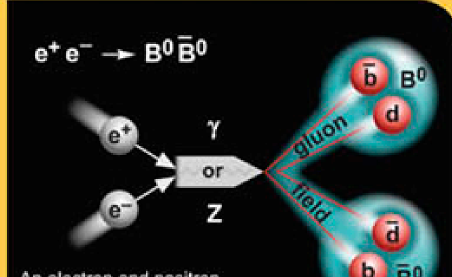


### Particle Processes

These diagrams are an artist's conception. Blue-green shaded areas represent the cloud of gluons.




A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.

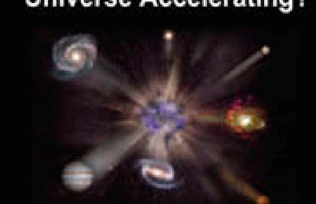



An electron and positron (antielectron) colliding at high energy can annihilate to produce $\bar{B}^0$ and $B^0$ mesons via a virtual Z boson or a virtual photon.

### Unsolved Mysteries

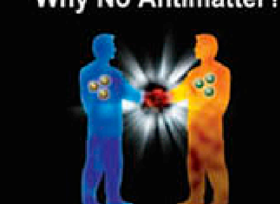
Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Experiments may even find extra dimensions of space, mini-black holes, and/or evidence of string theory.

**Universe Accelerating?**



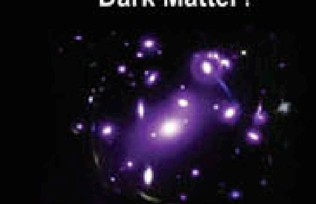
The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

**Why No Antimatter?**



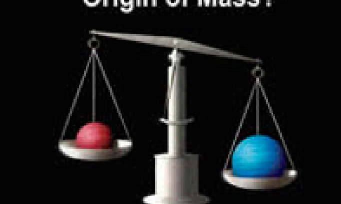
Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

**Dark Matter?**



Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

**Origin of Mass?**



In the Standard Model, for fundamental particles to have masses, there must exist a particle called the Higgs boson. Will it be discovered soon? Is supersymmetry theory correct in predicting more than one type of Higgs?